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A Visibility Characterization Program for Optical Communications Through the Atmosphere

K. Cowles
Communications Systems Research Section

A program is described for characterizing the atmosphere as it affects optical communications from a spacecraft. Cloud cover patterns and optical transmission will be determined by setting up three automated observatories in the Southwestern United States. Methods of site selection and operation of hardware and software components are presented, as well as plans for term deployment.

I. Introduction

Optical communication links to a ground-based station or network from a spacecraft experience degradation from the atmosphere. Cloud cover and other atmospheric effects can greatly attenuate laser signals or prevent transmission. The Atmospheric Visibility Monitoring (AVM) Program has been created to validate models for the effects of the Earth's atmosphere on optical communications. Three automated photoelectric telescopes (APTs) will be deployed in the Southwestern United States to measure atmospheric attenuation and determine cloud cover patterns. The telescopes will be located in areas that exhibit low correlation of weather patterns in order to determine the maximum percentage of time during which at least one area has favorable atmospheric conditions for deep space optical communications.

II. Preliminary Weather Model

A study conducted early in the project found that three sites with low correlation of weather patterns yield a joint visibility probability of 94 percent [1]. Fewer sites do not yield a probability of clear skies sufficient for reliable communications. (Two sites yield an 83 percent probability.) More sites do not provide enough improvement for their additional cost. (Four sites yield a 97 percent probability.) An extensive investigation of sites and site characteristics was then begun to determine what characteristics are most important to the AVM project and which sites possess them.

III. Site Selection Criteria

Only sites in the Southwestern United States were considered since they hold the highest percentage of days with clear skies in the continental United States [2]. For ease of travel, no sites out of the country were considered. Nor were sites in Hawaii considered because they would be too far away from the mainland sites to measure any significant spatial correlation of weather, and because of the higher cost of Hawaiian travel. If only one site were going to be used, or if a "belt" of sites were to be strung around the Earth (experimental or operational), Hawaii would be a prime choice for a site because of the excellent observing conditions and high probability of clear skies (90 percent on Mauna Kea).

Each site to be considered needs to exhibit other characteristics, such as low probability of cloud cover, fog, smog, and haze; low particle scattering; and low turbulence. These characteristics are discussed in depth in another report [3]. Since the telescopes are to be run remotely, there is also a need to locate them at present observatory sites so that someone can be on-hand to do maintenance and handle emergencies. There needs to be a degree of security to protect the system. Power, telephone lines, and roads also need to be easily accessible. All of the criteria have been weighted according to their importance to the program so that an educated decision can be made about which sites possess the best of the most important qualities [3].

IV. Candidate Sites

A search of sites in the southwest that presently have observatories was conducted, and further research was done to determine which sites possess favorable conditions. These sites include Mt. Hamilton, Table Mountain Observatory (TMO), Mt. Wilson, and Mt. Laguna in California; Mt. Hopkins, Mt. Lemmon, and the Hualapai Indian Reservation in Arizona; South Baldy and Sacramento Peak in New Mexico; and Mt. Locke in Texas. Other sites originally considered but eliminated for various reasons are Anderson Mesa, Mt. Graham, and Kitt Peak in Arizona; and Palomar and Goldstone in California. Goldstone was eliminated at this time because it is a very poor optical site. Its low elevation and location in the desert give rise to large amounts of particle scattering, turbulence, and atmospheric attenuation. Particle scattering is of great importance to the project because with large amounts of scattering, as is found at Goldstone, the number of stars able to be detected during the day is greatly reduced. Turbulence has been measured to be as much as ten times greater at Goldstone than at other sites.

The present sites have been split up into three categories by geographic location and general weather patterns in order to analyze the expected weather correlation factor between sites. The first category includes sites in southern California that experience storms from January to March: Mt. Wilson, TMO, and Mt. Laguna. The second includes sites in southern Arizona that experience storms in July and August: Mt. Hopkins and Mt. Lemmon. Areas in these two categories are known to be quite good for observing and have low correlation of weather patterns.

The question then arises as to where to locate the third telescope system. All the other sites fall into the third category. They exhibit some of the same weather as the first two categories, only there might be a time lag, or the storms might not be as severe or as large when they are passing over the site. The site having the lowest correlation with the others while still having a considerable amount of cloud-free hours needs to be determined. The best way to determine this is to analyze satellite data collected over several years, comparing cloud cover at the rest of the sites with the ones in southern California and southern Arizona. These data are being acquired and will be used to determine cloud cover patterns, including the size of an average storm and the time frames in which storms travel, over each site. The site that is clear the most often when both southern California and southern Arizona are cloudy should be the site picked for the third telescope.

The satellite data can also be used after the study has acquired some of its own cloud cover data to determine if the relatively short study is in fact a representative sample of weather conditions or if special conditions apply to the years for which AVM data are collected.

Three of the mountains have been visited, and excellent locations for the telescope systems have been found at each site. These mountains are Mt. Hopkins (Fig. 1), the Hualapai Indian Reservation (Fig. 2), and most recently, Mt. Wilson. The directors of the observatories were interested in this program and felt there would not be any difficulties in acquiring sites for the project should these three mountains be chosen [3].

V. System Hardware

Meade 10-inch Schmidt-Cassegrain telescopes are to be used to monitor starlight transmission through the atmosphere. Optec SSP-3A solid-state photometers are to use different filters mounted on a filter slider to count photons from each star. The mounts for the system, along with roll-off roof enclosures, are being manufactured by Autoscope Corp. The mounts have right ascension and declination drives that can step in increments of 0.46 arcsec. The enclosures have a 1/2 horsepower motor that can open and close the roof in case of inclement weather. Photos of the telescope, mount, and enclosure are shown in Figs. 3 and 4. A weather station is attached to each enclosure to measure wind speed, wind direction, barometric pressure, and temperature, and to detect precipitation. Alarms are set off for conditions of high wind speed, extreme temperature, or precipitation. Uninterruptible power supplies (UPS) supply emergency power in case there is a sudden power outage. If the power goes out, a UPS supplies enough power to close the roof until power is reconnected. All of the equipment is controlled by International Business Machines personal computer (PC)-AT compatibles that are able to communicate with a MicroVAX II over telephone lines via modems. WWV clocks are connected to the computers to keep accurate time, allowing for faster acquisition of stars. WWV clocks are radios that monitor a satellite clock. A heat exchanger is attached to the enclosure housing the electronics to keep them cool. All of the equipment is being integrated by Autoscope Corp. since they are also writing the software to control the equipment. Each individual observatory is to be assembled and tested on the Mesa at JPL. Since the Autoscope system is only designed for nighttime use, some slight modifications in hardware may be required to allow daytime detection.

To enable more efficient acquisition of the stars, additional hardware, namely a charge-coupled device (CCD) camera for faster nighttime centering, a second photometer modified for daytime use, and an instrument selector to move between these devices, may be added.

VI. System Software

The software that will control the telescope and enclosure and analyze the data received by the photometer and weather sensors is being written by Autoscope Corp. A large portion of this software will need to be rewritten to accommodate the needs of the AVM project. In its present state, the Autoscope software will accommodate typical astronomy applications for nighttime photometry. Some functions of the present software will not be used, and some code will need to be added to do tasks specific to this project, especially daytime photometry. These modifications should not be extensive. The code will be written in Turbo Pascal.

Telescope and enclosure control are to be entirely run by the PCs, although they can be manually run for testing purposes. There are audible alarms for conditions that cause the roof to close or open. Alarm conditions, as well as other operating conditions such as weather, time, zenith angles, etc., are recorded along with the data. The system should be able to run for several months with only short checks by local personnel.

The data that is received from the telescope photometer and the weather sensors will need to be compiled into a data base and analyzed. It will be transferred from the PCs at the sites to a MicroVAX II computer at JPL, where reduction and correlation algorithms will enable presentation of the data in an interpretable form.

VII. Daytime Viewing

Several different techniques that were considered for detecting cloud cover and transmission during the day are discussed in another report [4]. It was decided that the best method is to modify the photometer and software to allow daytime photometry. This makes possible the gathering of the same type of data as is gathered at night and the reception of atmospheric transmission as well as cloud cover data, although it will not be possible to search the sky as finely as at night.

The determination of where to locate the third telescope needs to wait until the satellite data on each area have been analyzed. Once tested and deployed, the telescopes can begin acquiring the data necessary to determine percentage of cloud cover, correlation effects, and atmospheric transmission.

VIII. Conclusions

An experimental data collection program for analysis of optical atmospheric transmission and verification of existing optical communications models has been described. A thorough study to determine the characteristics and locations of the sites for the telescope systems is almost completed. Site selection is an inexact science, as weather and other atmospheric conditions are constantly changing. Past years of satellite data will help to establish common yearly conditions for each location.

The AVM telescope systems have been configured and will be operating on the Mesa after slight modifications to the hardware. There is still a large amount of software that will need to be incorporated for telescope control and data reduction.

References

[1] K. Shaik, "A Preliminary Weather Model for Optical Communications Through the Atmosphere," *TDA Progress Report 42-95*, vol. July-September 1988, Jet Propulsion Laboratory, Pasadena, California, pp. 212-218, November 15, 1988.

[2] R. Lynds and J. Goad, "Observatory Site Reconnaissance," *Publications of the Astronomical Society of the Pacific*, vol. 96, pp. 750-766, September 1984.

[3] K. Cowles, "Site Selection Criteria for the Optical Atmospheric Visibility Monitoring Telescopes," *TDA Progress Report 42-97*, this issue.

[4] D. Erickson and K. Cowles, "Options for Daytime Monitoring of Atmospheric Visibility in Optical Communications," *TDA Progress Report 42-97*, this issue.

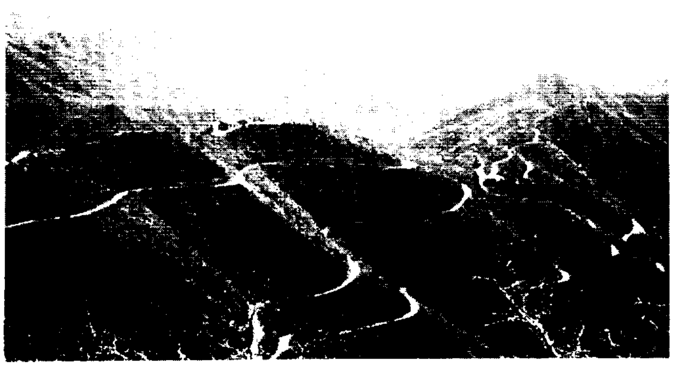

Fig. 1. Mount Hopkins. The AVM systems could be located on the knoll farthest to the left in the foreground.

Fig. 2. Hualapai Indian Reservation. The AVM systems could be located on the plateau to the right.

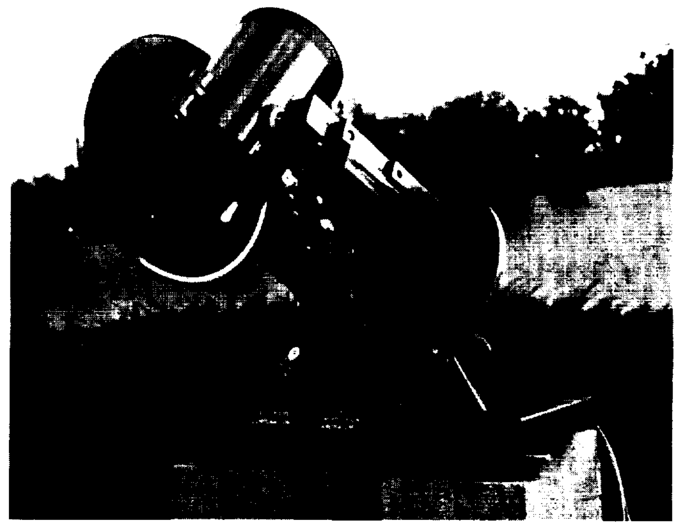

Fig. 3. AVM telescope and mount.

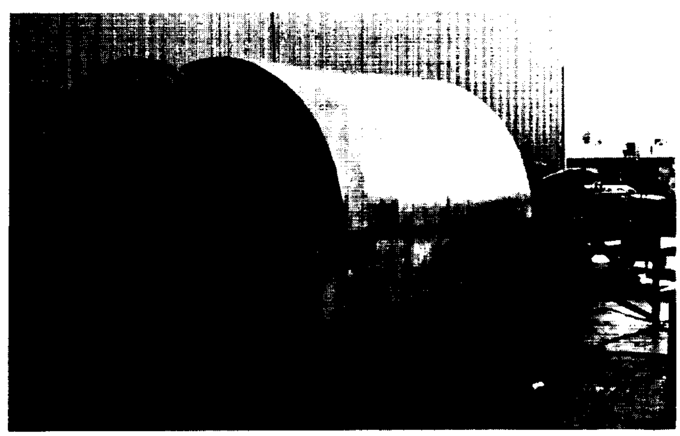

Fig. 4. AVM telescope enclosure with roll-off roof.

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Options for Daytime Monitoring of Atmospheric Visibility in Optical Communications

D. Erickson and K. Cowles
Communications Systems Research Section

Techniques for daytime detection of atmospheric transmission and cloud cover to determine the capabilities of future deep-space optical communications links are considered. A modification of the planned nighttime photometry program will provide the best data while minimizing the need for further equipment. Greater degrees of modification will provide increased detection capabilities. Future testing of the equipment will better define the improvement offered by each level of modification. Daytime photometry is favored at certain wavelengths because of higher transmission and lower background noise, thus giving an increased signal-to-noise ratio. A literature search has provided a list of stars brighter than second magnitude at these wavelengths.

I. Introduction

The Atmospheric Visibility Monitoring (AVM) program will monitor the presence and correlation of cloud cover and transmission through the atmosphere at certain laser wavelengths to determine the feasibility of accommodating a cluster of ground-based optical communications transceivers. The sky must be continuously monitored, 24 hours a day, to detect clouds and transmission at varying zenith angles. At night, starlight will be detected using differential stellar photometry from three automatic photoelectric telescopes (APTs) on mountains in the southwestern United States. Equipment for nighttime photometry has already been purchased. During the day, detection of clouds and measurement of atmospheric transmission using stellar photometry are more challenging because of the background noise caused by scattered sunlight. Several different options were considered for use in monitoring the atmosphere during the day.

II. Criteria

The criteria which need to be met by a daytime AVM detection scheme are as follows:

(1) Detect the presence of clouds as a percentage of sky cover

(2) Monitor the entire sky, especially near the ecliptic, throughout the day

(3) Measure atmospheric transmission at varying zenith angles

(4) Maintain autonomous operation

(5) Keep additional equipment costs to a minimum

(6) Require minimal maintenance (a system could operate for periods of 2–3 months without trained personnel traveling to the site for maintenance)